

# Methodology for Analyzing Multi-Temporal Planimetric Changes of River Channels

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**Abstract.** In this study we describe a methodology for quantifying planimetric changes of river channels between two epochs. Different cartographic, photogrammetric or remote sensing products capable of measuring distances in a CRS such as orthoimages, maps, etc. are proposed to be used in order to obtain the digitalized linestrings of the boundaries and subsequently the axes of the river sections in different epochs. The displacement values of axes are obtained using a proposed methodology for positional quality control based on linear elements. The methodology also includes the positional quality control of both spatial data sources using a set of control points and the calculation of the planimetric RMSE and the derived NSSDA accuracy. This control provides the relative positional accuracy between both data sources, determining the minimum displacement value to be significant. The methodology has been applied to the Guadalquivir River in Spain using more than 470 km for each epoch, obtained from two orthoimages. The results show local and global displacements of the river which can be used to analyze hydrological behavior or to determine changes due to infrastructures built by man.

**Keywords:** Temporal change detection, River channel, linestring displacement.

## 1. Introduction

The study of changes of river channels has great importance due to the economic, environmental and social consequences that these displacements can produce. From a multi-temporal study some conclusions regarding the behavior of the river can be obtained such as predictions about possible alterations of the course and establishing a level of hazards in function of physical or human factors. In this sense the current geomatic techniques

help in analyzing the river channels and their modifications due to the great quantity of spatial data which are available and the accuracies achieved. Among these techniques we can highlight those which use images such as photogrammetric flights, remote sensing, LiDAR and their derived products (orthoimages, DEMs, etc.) because they allow the development of regional scale studies and other techniques (close range photogrammetry, Terrestrial Laser Scanner, surveys using total stations or GNSS, etc.) for local scale studies (e. g. Pyle et al. 1997, McKean et al. 2009). In general the geometric studies of the river channels are mainly developed in order to analyze hazards, economic and environmental effects or the consequences of human alterations (e. g. the building of a dam). These studies use the analysis of cross sections of the river, the comparison of DEMs, etc. and are widely described in the literature (Mohammed-Aslam & Balasubramanian 2010).

Although these types of studies are centered on the aspects previously described, the movements of the river channels also affect the positional quality of a Spatial Database (SDB). In this sense an SDB can contain geographic elements with high positional accuracy and positional stability but they can also contain a river which has been displaced, in some sections, from the acquisition time of the data. Thus the positional component is highly related to the frequency of data updating (temporal component of the accuracy NCDCCDS 1989, ISO 1999). Our point of view is that the analysis of the positional accuracy of an SDB must take into account these elements, firstly because they are part of the SDB with a defined level of accuracy (even tested by a standard like USGS 1947, ASCE 1983, ASPRS 1990, FGDC 1998), and secondly because the users of the SDB also demand to know the correct position and the accuracy of these elements. Thus the multi-temporal analysis of the movements of the river channels should allow the establishment of a certain level of positional accuracy for each section of the river related to time. In this context this study proposes a methodology for performing a multi-temporal analysis of the movement of the river channels by the extraction of the mean axes and their comparison using positional control techniques based on linear elements. In order to perform this analysis, the river is segmented in function of some criteria such as the locations of tributaries, the existence of dams, etc.

The study of the positional accuracy of linear elements has been carried out taking into account the uncertainly band or Epsilon band around the most probable position of the line. This band was described by Perkal (1956) and subsequently its description was extended by, among others, Caspary & Scheuring (1993) and Shi & Liu (2000). Several techniques have been described in order to determine the accuracy of these kinds of elements of an SDB based on this concept. Thus there are some methods for determining the positional accuracy of linear elements based on the calculation of dis-

tances or areas between the line to be controlled and a control line selected from a more accurate source such as those described by Abbas et al. (1995) and Skidmore & Turner (1992), or based on buffers generation such as those described by Goodchild & Hunter (1997) or Tveite & Langaas (1999). Mozas & Ariza (2011) described a method based on the determination of the minimum Euclidean distance between the vertexes of one line with respect to the other line and the weighting of the detected displacements based on the lengths of the adjacent segments to the vertex. This method is applied in this study to the axes of the river channels.

Taking into account these backgrounds, this study describes a methodology for determining the displacements between the axes, in two epochs, of the river channel considering these axes as linear elements in order to obtain their relative positional discrepancies. The methodology also includes the quantification of the positional relative error of both sources of data (both SDBs) using the root mean square error, RMSE, using control points that are unambiguously defined in both SDBs. Finally we determine the NSSDA accuracy based on the RMSE value.

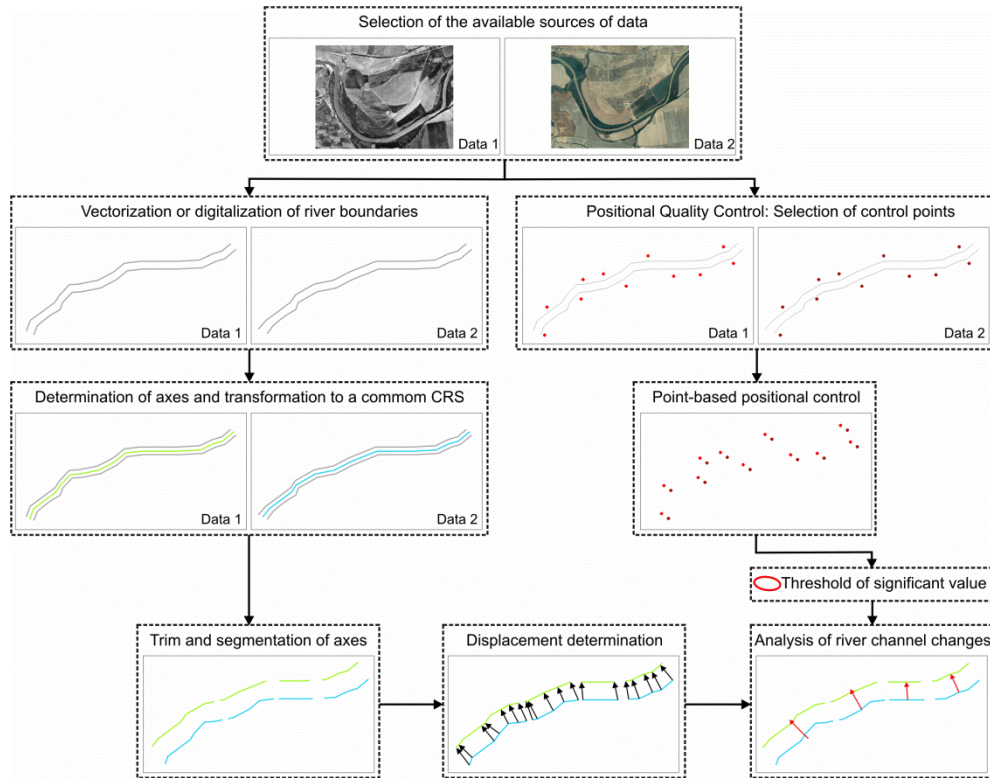
The methodology has been applied to the Guadalquivir River (located in Andalusia – Spain) using the existing orthoimages of years 1956 and 2007. The results have allowed us to determine sections of the river with significant displacements and sections with lesser changes.

## **2. Methodology**

The methodology followed in this study is shown in *Figure 1*. It starts with the selection of the available sources of data corresponding to the two epochs to be analyzed. These data can be obtained from the vectorization or digitalization of images or directly from an SDB which contains the boundaries or the axes of the river.

For a more general study we will consider that the boundaries of the river are obtained from their digitalization using two orthoimages corresponding to two epochs (Data 1 and Data 2 in *Figure 1*). An important issue to take into account when digitizing the boundaries of the river is the visibility of the boundaries in the images. Boundaries of the river tend to be hidden mainly due to the occlusions derived from the dense vegetation. In this sense there are sections of the river where the boundaries are not clearly defined and this methodology cannot be applied. An alternative way to determine the axes of the river should be found for these cases. Using the digitalized boundaries, the linestrings representing the axes of the river channel can be easily obtained. In our case, the methodology has applied a triangulation algorithm to obtain these axes. All data must be transformed to the

same Coordinate Reference System (CRS). Subsequently both linestrings are compared by manually trimming those sections which are not in the other set of data and by segmenting the axes, taking into account the location of main tributaries and new infrastructure presence (e. g. bridges, dams, etc.).

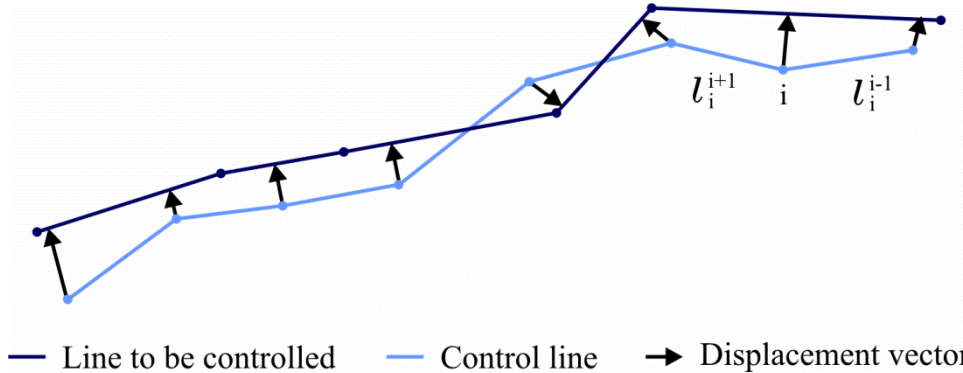


**Figure 1.** Proposed methodology.

Once the equivalent axes of the river channel in both epochs are obtained, the positional evaluation between both sets of linestrings is carried out. For this purpose we propose using the VIM method described by Mozas & Ariza (2011) which provides a method for comparing the positional aspect of two sets of lines. It consists of the determination of the minimum Euclidean distances and their planimetric components for each vertex of one line with respect to the other line (control line and line to be controlled respectively, see *Figure 2*).

The selection of the set of control lines is derived from a more accurate source in an absolute positional control, but in this case of relative control, the criterion for selecting the control line is the number of vertexes. Thus the linestring of axes with the highest number of vertexes is considered as

the control line. Once the distances and XY components are calculated, the average values are determined by weighting the distance or component by the length of the adjacent segments to the vertex used. For example, in *Figure 2* the distance of the vertex  $i$  is weighted using the length  $l_i^{i+1}$  and  $l_i^{i-1}$  of the adjacent segments. In the same way the mean value of the components X and Y are calculated.



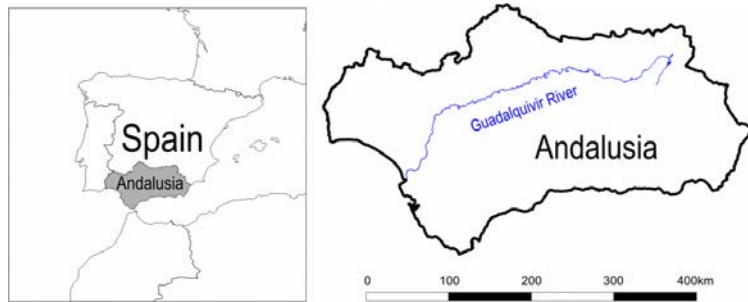
**Figure 2.** VIM method (Mozas & Ariza 2011).

The selection of the VIM method is due to several factors: its efficiency, the usual great quantity of vertexes of these elements and mainly, the fact that this method allows us to obtain a displacement vector for each section of the river channel. The result of its application is a set of displacement vectors which are analyzed taking into account the relative positional accuracy between sources of data. So a relative positional quality evaluation is carried out following the standard NSSDA (FGDC 1998) using a set of control points which are time-stable, well-defined and well-distributed along the river. The NSSDA planimetric value obtained will be used as the significant limit value in order to establish the threshold of the minimum displacement value.

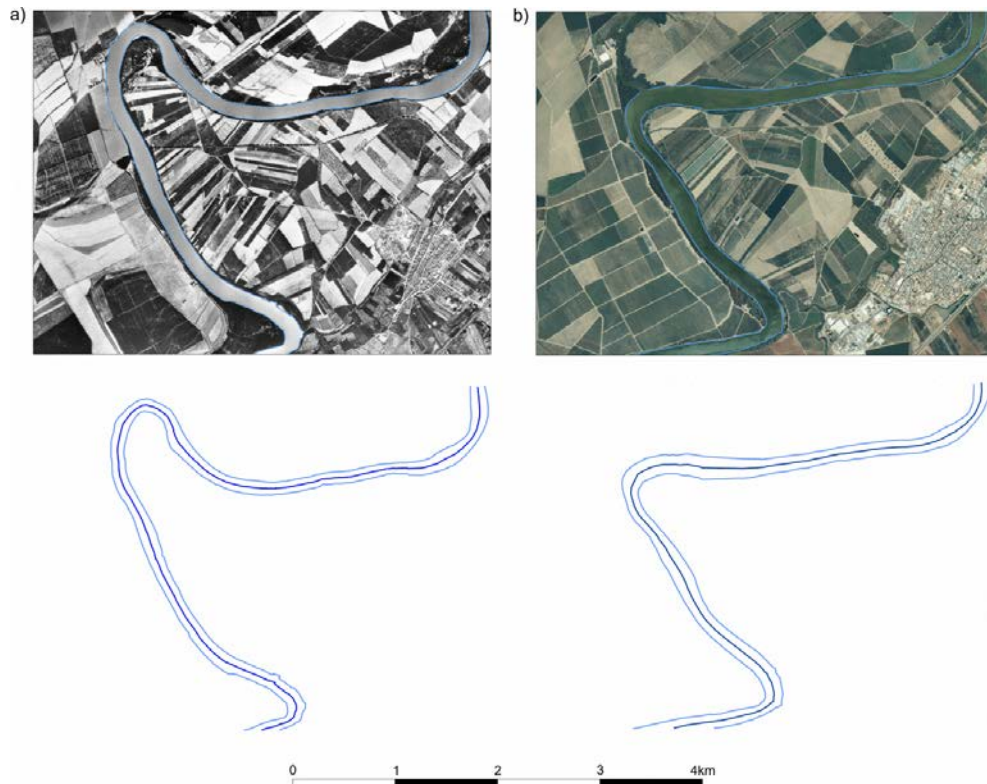
### 3. Application

The proposed methodology has been applied to the Guadalquivir River (*Figure 3*) (main river of Andalusia in southern Spain) using more than 470 km for each epoch. Two sets of orthoimages have been used (mosaics composed of more than 80 images) distributed by the Instituto de Estadística y Cartografía de Andalucía (Spain) corresponding to flights developed in the years 1956 (ORTHO1956) and 2007 (ORTHO2007). Both sets of orthoimages have a spatial resolution of 1 meter, are referenced in the same CRS (EPSG 23030) and are part of the historical orthoimages production of

the REDIAM (Environmental information network of Andalusia) (Vales et al. 2010).



**Figure 3.** Study Zone: Guadalquivir River.

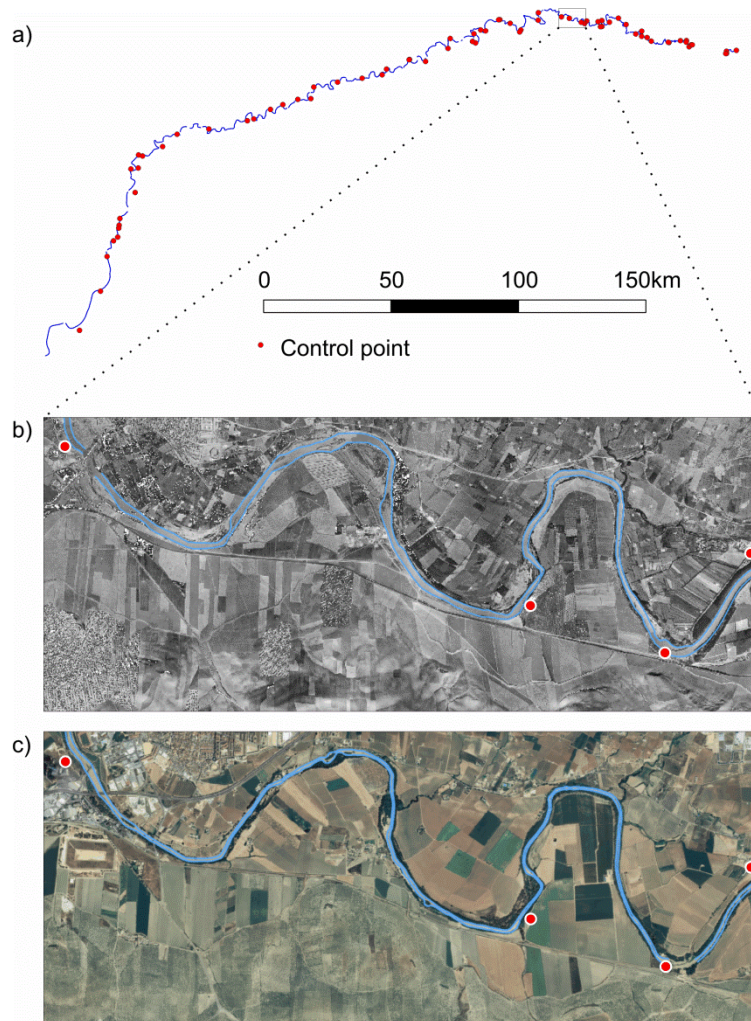


**Figure 4.** Example of digitalization of the boundaries of the river and axes determination: a) ORTHO1956; b) ORTHO2007.

The digitalization of the river boundaries was carried out by the same operator using the Quantum GIS edition tool. After that, the axes were obtained and the processes of comparison and trim of the ends of the axes performed



in order to obtain the same sections of the river channel (no vertex displacement was applied). These procedures were carried out using AutoCAD™ tools. The axes were segmented into 60 sections following the criteria explained in the methodology (*Figure 4*). The application of the VIM positional control method was developed using CPLin software developed by Mozas & Ariza (2011).



**Figure 5.** Control Points: a) General distribution; b) Detail of control points on ORTHO1956; c) Detail of control points on ORTHO2007.

Finally, the control points were selected and digitalized using Quantum GIS. More concretely, a well-distributed set of 74 control points was captured in order to determine the relative positional accuracy between both spatial data sources (*Figure 5*). The control points are located close to the

river and were selected among buildings, crossroads, etc. All of them are time stable.

#### 4. Results

The first result obtained after applying the methodology to the orthoimages previously described was the extraction of a set of axes and boundaries of the river channels for both epochs. These axes can be easily compared visually by superimposing the images, as is shown in the examples of *Figure 6*. In these cases the river course has experienced large movements in some sections (cases *a*, *b* and *c*), while in other sections the displacements are lesser (cases *d*, *e* and *f*). In the first cases, the axis of the river has clearly been affected. We highlight that the case *Figure 6c* was due to the human alteration of the course of the river. Another issue to be taken into account is the width of the river at the acquisition time. The case shown in *Figure 6e* shows that the boundaries of the river in 1956 are farther apart than the boundaries of ORTHO2007. However the axes are closely coincident. This explanation justifies the use of the axes in order to provide a planimetric positional analysis.

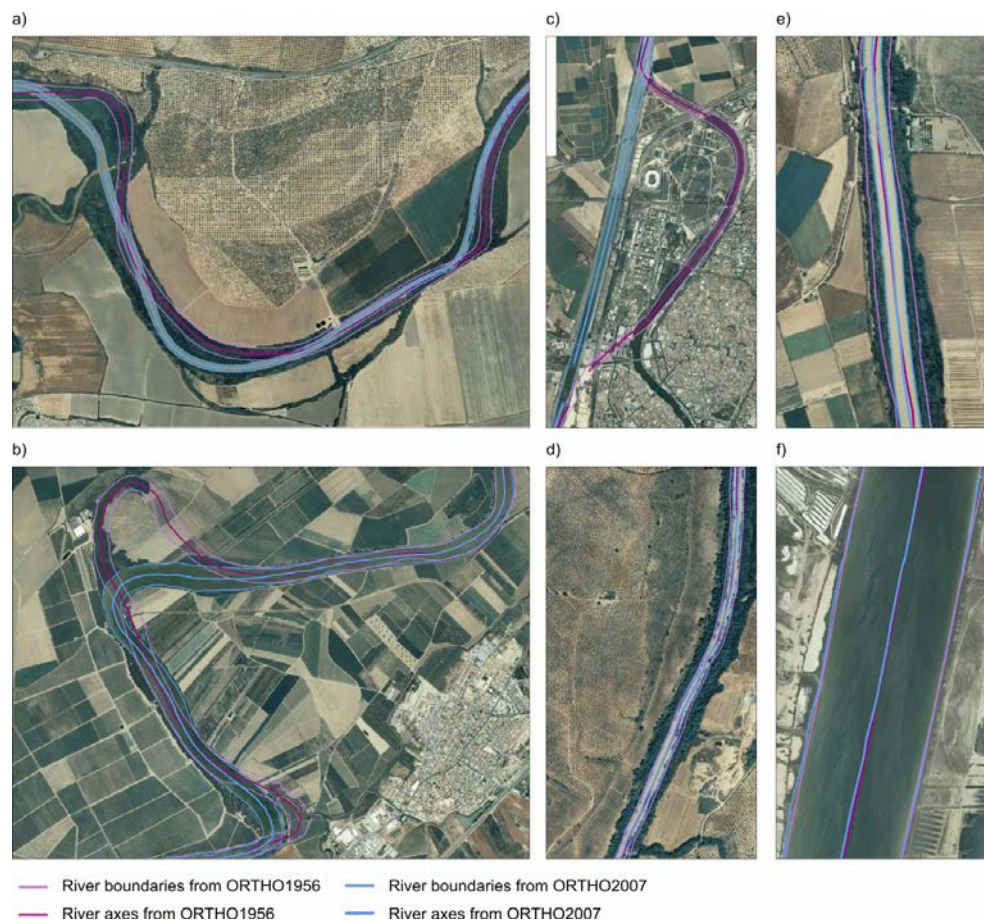
The main results obtained when applying the positional control methodology (VIM method) to both sets of linestrings are shown in *Figure 7*. The graph in *Figure 7a* shows the VIM distances for each linestring. The widths of bars represent the length of the linestrings. The majority of cases show displacement values lower than 50m. However there are some cases with higher displacement values. These cases (e. g. that shown in *Figure 6c*) are related to important changes in the river course mainly due to human alterations.

The analysis of the XY components for each line is shown in *Figure 7b* and *Figure 7c* using displacement vectors between ORTHO2007 (control lines) and ORTHO1956 (lines to be controlled). The displacement vectors obtained confirm the behaviors detected in *Figure 7a*.

With regards to the analysis of both datasets the RMSE is 12.32m which determines a NSSDA, relative positional accuracy between both orthoimages shown (*Figure 8*) of 21.32 meters (19.8m for Easting and 22.7m for Northing). So we establish this distance as the threshold of significant value for this case. The 43.43% of the length of the linestrings is below this threshold (see *Figure 7a*). Consequently the mean displacements of these sections are not significant using these data sources. The 49.19%, 88.53% and 97.33% of the length of the linestrings has a displacement lower than 25m, 50m and 100m respectively. Only some sections of the river close to the mouth have higher mean displacements than 100m (*Figure 7*).



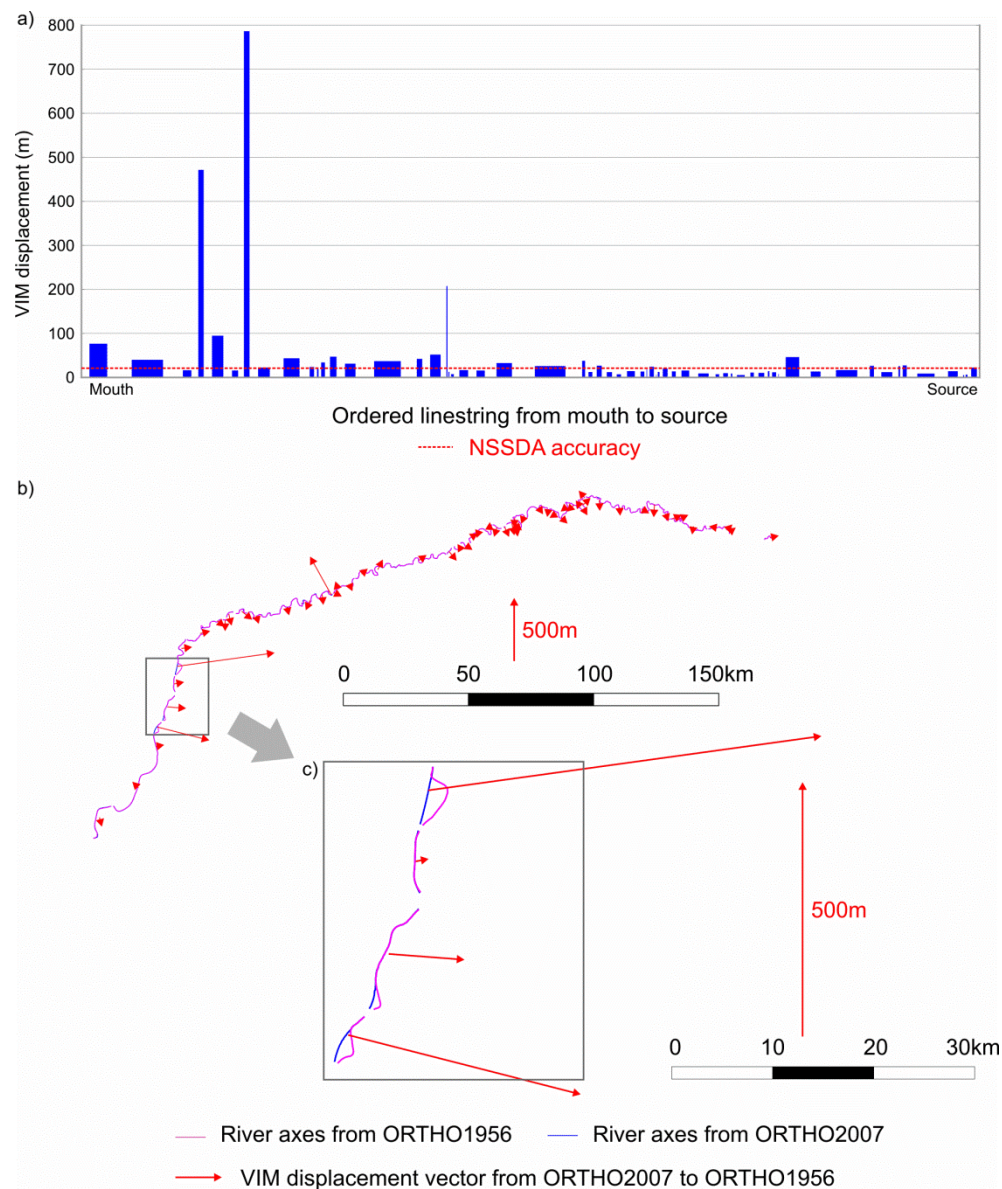
The displacements detected in *Figure 8* using control points seem to be well-distributed throughout the zone of study. There are some zones with similar displacements between adjacent points (module and orientation). This is due to geo-referencing errors in some orthoimages (probably from some sheets of ORTHO1956). The 71.6% of control points have a displacement lower than the RMSE value and the 94.6% lower than the NSSDA accuracy.



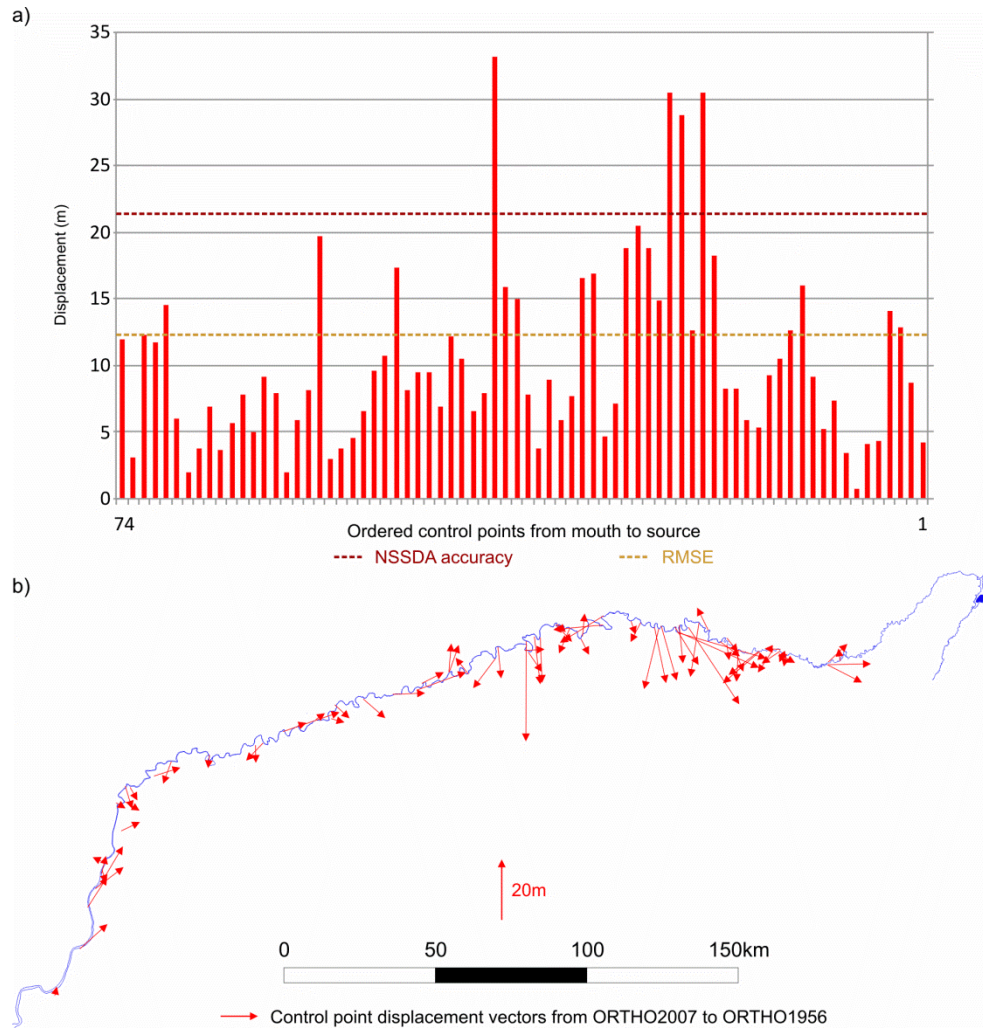
**Figure 6.** Examples of detected cases: a) and b) Important changes of the river course; c) changes derived from human action in the course; d) and e) sections without significant changes in the upper and medium course; f) sections without significant changes in the mouth.

Finally, the proposed methodology has allowed us to obtain a general point of view about the behaviour of the river between both epochs. Some sections of the river have been affected by important changes in their course and these sections are detected by the method. The information obtained

also allows a more local analysis of some sections in order to study local displacements. Thus the results can be used to determine local and global displacements of the river in order to analyse its hydrological behaviour or determine changes due to infrastructures built by man.



**Figure 7.** VIM Results: a) Displacement by linestring (widths represent the lengths of linestrings); b) Displacement vectors; c) detail of highest displacement vectors.



**Figure 8.** Results of position evaluation using control points: a) Displacements by point; b) Displacement vectors.

## 5. Conclusion

In this study we describe a methodology for detecting movements of river channels by means of their axes using a positional quality evaluation method. The displacements are affected by the accuracy of the data sources. For this reason a significant value is required. This threshold is obtained by applying a positional quality evaluation method based on points. In our case we propose the NSSDA. Taking this threshold into account, the methodology allows us to determine the significant displacement vectors of the

axes of the river channels between two epochs. Using the displacement vectors we can describe the river's behavior.

The methodology was applied to more than 470km of the Guadalquivir River, showing that about 56% of the length of digitalized linestring are displaced a significant value. However about 88% have a displacement lower than 50 meters. Thus some cases of higher displacements are detected related to changes in the course of river (mainly by human alterations). Therefore the methodology allows the determination of displacement vectors between different epochs. So we could establish a mean displacement velocity for each section of the river and determine a variation index in function of time.

The digitalization of boundaries is a key factor in obtaining the axes of the river channels, thus affecting the displacement vectors. So problems in determining the boundaries of river channels (e. g. due to occlusions in images) are not solved in this methodology and will require further study.

## Acknowledgements

This work has been partially funded by the European Regional Development Fund (ERDF) and by the National Ministry of Science and Technology of Spain under grant n° BIA2011-23271.

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